

# The Quantum Interference Computer: error correction

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## Abstract

An error correcting mechanism is proposed in the context of the Quantum Interference Computer approach

## 1 Introduction: Computing with the quantum

The logical bit (binary digit) is the fundamental concept in classical digital computing and can take on the state representing 0 or 1. In contrast, the world on a small (atomic) scale obeys differing rules described by quantum theory, which has the qubit that can be a linear superposition of these two states:

$$|\phi\rangle = \alpha |0\rangle + \beta |1\rangle \quad (1)$$

a seemingly small change that has many profound consequences, where the amplitudes  $\alpha$  and  $\beta$  are complex numbers, and are the analog part of quantum theory. However, and in contrast, when we measure such a state we actually get the result 0 or 1 (the state has collapsed) with probabilities  $|\alpha|^2$  for  $|0\rangle$  and  $|\beta|^2$  for  $|1\rangle$ , such is the nature of the quantum world and this is the digital aspect of quantum theory where conservation of the system (unitarity) demands that  $|\alpha|^2 + |\beta|^2 = 1$ . Why the world is like this, nobody really knows, and it disturbed Einstein to such an extent that he stated that ‘God does not play dice’; but without such a mechanism, we would be denied freewill, so it is a good thing that the world is the way that it is.

In the large world such interactions are happening all the time, and that is why we are not used to seeing the direct effect of these combinations. It takes a lot of care to avoid a measurement happening until one is

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ready, and this is part of the difficulty in building a quantum computing device.

So here we see the nature of the quantum way, where, although both bit types are involved, only one is seen upon measurement. There are features of an analog system (the continuous numbers  $\alpha$  and  $\beta$ ), while the act of measurement carries discrete, or digital, aspects.

We have avoided delving on the more subtle and strange aspects of quantum theory at this juncture, and if necessary one can adopt a pragmatic Engineering approach.

## 1.1 The parallel nature of quantum theory

Because the quantum state carries both digits at once, unlike the classical, there is the prospect of performing many calculations in parallel. This is seen even more clearly for a 2 qubit quantum system, whose state would look like:

$$|\psi\rangle = \alpha_{00} |0\rangle |0\rangle + \alpha_{01} |0\rangle |1\rangle + \alpha_{10} |1\rangle |0\rangle + \alpha_{11} |1\rangle |1\rangle \quad (2)$$

while in general an  $n$  qbit system has  $2^n$  components. This exponential growth in size is at the potential core of the power implicit to quantum computing, and is of such an enormous advantage that a system with just 300 bits would have more states than there are atoms in the visible Universe (about  $10^{80}$ ). This leads one to pondering how or where all these calculations are performed and held, and such questions remind us why Physics once went under the name of Natural Philosophy.

The above state is often written more compactly as:

$$\alpha_{00} |00\rangle + \alpha_{01} |01\rangle + \alpha_{10} |10\rangle + \alpha_{11} |11\rangle \quad (3)$$

and if one were then to apply a function ( $f$ ) to this one state, Nature's quantum engine would effectively apply it to all components, yielding:

$$\alpha_{00} f(|00\rangle) + \dots + \alpha_{11} f(|11\rangle) \quad (4)$$

The ability to do so very much computing in one application is the good part; how this is actually achieved by Nature is not known.

## 1.2 The restrictions of measurement

The problem (or bad part) arises upon the act of measurement, when, as mentioned above, one only sees one of the parts with due probability. As a result no advantage has been taken of the fact that the quantum

world has all that computational power, and this is exactly why quantum computers seem to be so hard to program.

Rather than detour at this point into a discussion of the various restricted approaches to date known to overcome this obstacle, we consider an alternative proposal that might show promise of a generic way around this dilemma.

## 2 A review of the Quantum Interference approach

Interference has been proposed as an amplifying mechanism for quantum computation [1, 2]. How it is supposed to work is illustrated by the following.

Start with the following three qubit Hadamard state for illustration (leaving out normalizations for clarity)

$$|\psi\rangle = (|0\rangle + |1\rangle)(|0\rangle + |1\rangle)(|0\rangle + |1\rangle) \quad (5)$$

$$= |000\rangle + |001\rangle + |010\rangle + |011\rangle + \dots + |111\rangle \quad (6)$$

and like Grover's algorithm, apply the decision function to mark the invalid solutions by inverting their phase. For the sake of argument let us suppose that the solutions 001 and 011 satisfy the function, which yields the state:

$$-|000\rangle + \overbrace{|001\rangle}^{\text{Solution}} - |010\rangle + \overbrace{|011\rangle}^{\text{Solution}} - \dots - |111\rangle \quad (7)$$

which has got us nowhere at all, *unless* one were to bring in the mechanism of Young's double slit or the beam splitter interferometer, with the marking function being applied to one of the two arms alone. Then interference of the arms would yield:

$$\begin{aligned} & -|000\rangle + |001\rangle - |010\rangle + |011\rangle - \dots - |111\rangle \\ & + |000\rangle + |001\rangle + |010\rangle + |011\rangle + \dots + |111\rangle \end{aligned} \quad (8)$$

to expose the desired solutions

$$|001\rangle + |011\rangle \quad (9)$$

one of which will consolidate upon measurement, and can then be confirmed on a classical computer, if so desired. The two arms are brought into overlap and not sent through a final beam splitter as is typical of an interferometer.

To locate the remaining solution, one can start over, and exclude the known solution by also inverting its phase in one of the two interference arms. Eventually all solutions will be located and removed, so the final run will expose either a non-valid solution or a previously found solution from the remnants of the wave-function.

Concerns over lost unitarity can be allayed by noting that a quantum computer typically starts by transforming a sharp (ground) state into a superposition, and that this is a unitary change. All that is happening here is the inverse, and so the process is also unitary.

In practice, due to imperfect cancellation, this process may need to be repeated a few times before the act of measurement.

### 3 Error correction

As a calculation proceeds, invalid components will spontaneously appear in the superposition and these can be identified by adopting the classical checksum technique. These invalid calculations can then be removed at the end in the same manner as invalid solutions, as detailed above.

## References

- [1] A. Y. Shiekh, Int. Jour. Theo. Phys., 45, 2006, 1653  
[arXiv:cs.CC/0507003]
- [2] Gui Lu Long, Commun. Theor. Phys. 45(5), 2006, 825  
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